Development and Demonstration of Medium- and Heavy-Duty PHEV Work Trucks

Principal Investigator: John Petras

Organization: Odyne Systems, LLC

Date: June 22, 2021

Project ID: elt094

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Project Overview

Timeline:
• Start Date: January 19, 2017  
• Completion Date: January 31, 2023  
• Percent Complete: 75%

Barriers
• Fuel efficiency of Medium/Heavy-duty work trucks  
• Integration of Driving and Jobsite electrification of Medium/Heavy-duty work trucks  
• Over 50% of Work Truck fuel use occurs during stationary operation – not addressed by traditional Hybrid solutions

Budget
• Total project funding: $6,955,281  
  • DOE Share: $2,149,644  
  • FFRDRC Share: $782,549  
  • Contractor Share: $4,023,088  
• FY20 DOE Funding: $367,416  
• FY21 DOE Funding: $378,133  
  • Includes FFRDRC

Project Partners
• Odyne Systems – Project Lead  
• Freightliner Trucks  
• Allison Transmission  
• Ricardo Engineering  
• National Renewable Energy Laboratory  
• Oak Ridge National Laboratory  
• South Coast Air Quality Management  
• 2 Utilities - TBD

Any proposed future work is subject to change based on funding levels
Relevance / Objectives

- **Overall Objectives**
  - To develop and demonstrate an advanced Plug-in Hybrid Electric (PHEV) Medium-Heavy Duty Work Truck
    - With greater than 50% reduction in fuel consumption when compared to a conventional diesel vehicle baseline

- **Relevance**
  - Work trucks are unique in the proportion of fuel used during stationary activity and the diversity vehicle design and jobsite equipment utilized to fulfill their missions
  - Most hybrid work focuses on driving, ignoring the high stationary fuel use of the vocational market
  - This project will develop and demonstrate a modular PHEV Work truck solution which meets the needs of the work truck user while demonstrating a 50% reduction in full-day fuel use

- **Milestones**

<table>
<thead>
<tr>
<th>Milestones: Period 2</th>
<th>Date</th>
<th>Status 5/14/21</th>
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</thead>
<tbody>
<tr>
<td>Prototype Vehicle Functional Validation</td>
<td>October, 2019</td>
<td>Complete</td>
</tr>
<tr>
<td>Hardware in the Loop (HIL) Powertrain Verification</td>
<td>February, 2020</td>
<td>Complete</td>
</tr>
<tr>
<td>Prototype Vehicle Performance Validation (Go-No Go)</td>
<td>May, 2021</td>
<td>Finalizing Report</td>
</tr>
<tr>
<td>Evaluation Fleet Build and Delivery</td>
<td>December, 2021</td>
<td>On Track</td>
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Any proposed future work is subject to change based on funding levels.
Approach:
Plug-in hybrid propulsion+ work site idle reduction

Hybrid Powertrain

Stock Transmission  Electric Motor  PTO

Minimally Intrusive
Hybrid Power through existing PTO port
No Changes to Base Powertrain
Allison Approved – Retains Powertrain Warranty

Modular Design

Flexible
60 kW of hydraulic/pneumatic power
15 kW of 120/240VAC exportable power
Multiple OEM and Application platforms
- Same base hybrid system

Multiple Vocations

Any proposed future work is subject to change based on funding levels
Oak Ridge Simulation model was utilized to evaluate multiple iterations of refined Driving Strategies

Oak Ridge Hardware-in-the-Loop (HIL) Powertrain Dynamometer was utilized to validate the simulation and fine tune the driving strategies

Primary features resulting in improved fuel economy included:
- Increasing speed (MPH) range of Torque Assist
- Increasing Peak Torque Available
- Balance mode, reduce engine load by the amount hybrid motor is providing
- Idle Neutral

Results
- The combination of features above predicted fuel economy improvements of 34-51% over baseline diesel
- Two strategies were chosen for chassis dyno test
  - Aggressive – All the features evaluated
  - Mild – Closer to charge sustaining strategies with lower battery use per mile

Any proposed future work is subject to change based on funding levels
Technical Accomplishments
Finalize Design and Build Test Truck

- Design and integration into Test Chassis has been completed
  - Modular integration: 3 primary, 1 optional
- Final Subsystem Specifications:
  - 17.7 / 35.4kWh RESS
  - 250 Nm, 71 kW Peak, 150 Nm, 50 kW Continuous Motor Torque/Power
  - 12 kW Exportable Power (120V/240V)
  - 4 kW DC/DC 12V support
  - 3.3 kW J1772 Level 2 Charging
  - Independent WEG Cooling System
  - 17,000 btu Engine-off HVAC

Any proposed future work is subject to change based on funding levels
Technical Accomplishments
NREL System Test

- The Test Truck was tested at the NREL ReFUEL Dynamometer test facility
  - Mild strategy yielded 9.5 – 23% improvement in fuel economy
  - Aggressive strategy yielded 69 – 75% improvement in fuel economy
  - **Stationary Work Cycle**: Hybrid system yielded 80-99% improvement in fuel consumption and emissions
    - Worst case scenario assuming all energy derived from field recharge

### NREL Drive Cycle Test Results

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<tbody>
<tr>
<td>Conventional</td>
<td>UDDS</td>
<td>5.503</td>
<td>0.892</td>
<td>0.162</td>
<td>6.174</td>
<td>9.5%</td>
<td>0.000</td>
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<tr>
<td>Hybrid Mild</td>
<td>UDDS</td>
<td>5.498</td>
<td>0.813</td>
<td>0.148</td>
<td>6.762</td>
<td>9.5%</td>
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<tr>
<td>Hybrid Aggressive</td>
<td>UDDS</td>
<td>5.514</td>
<td>0.528</td>
<td>0.096</td>
<td>10.456</td>
<td>69.4%</td>
<td>0.971</td>
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<tbody>
<tr>
<td>Conventional</td>
<td>Odyne Low</td>
<td>3.782</td>
<td>0.809</td>
<td>0.214</td>
<td>4.678</td>
<td>0.000</td>
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<td>Hybrid Mild</td>
<td>Odyne Low</td>
<td>3.780</td>
<td>0.656</td>
<td>0.174</td>
<td>5.758</td>
<td>23.1%</td>
<td>0.508</td>
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<td>Hybrid Aggressive</td>
<td>Odyne Low</td>
<td>3.788</td>
<td>0.476</td>
<td>0.126</td>
<td>7.954</td>
<td>70.0%</td>
<td>1.675</td>
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<tbody>
<tr>
<td>Conventional</td>
<td>Odyne Medium</td>
<td>8.911</td>
<td>1.431</td>
<td>0.161</td>
<td>6.226</td>
<td>0.000</td>
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<tr>
<td>Hybrid Mild</td>
<td>Odyne Medium</td>
<td>8.907</td>
<td>1.226</td>
<td>0.138</td>
<td>7.266</td>
<td>16.7%</td>
<td>0.197</td>
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<td>Hybrid Aggressive</td>
<td>Odyne Medium</td>
<td>8.897</td>
<td>0.815</td>
<td>0.092</td>
<td>10.918</td>
<td>75.4%</td>
<td>1.220</td>
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### NREL Stationary Cycle Test Results

<table>
<thead>
<tr>
<th></th>
<th>NOx [g/kW-hr]</th>
<th>CO2 [g/kW-hr]</th>
<th>Fuel Cons [g/kW-hr]</th>
<th>Fuel cons FS [g/kW-hr]</th>
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</thead>
<tbody>
<tr>
<td>Conventional PTO first</td>
<td>51.303</td>
<td>4423.116</td>
<td>1390.698</td>
<td>1452.816</td>
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<tr>
<td>Conventional PTO - warm</td>
<td>62.001</td>
<td>4388.342</td>
<td>1380.650</td>
<td>1460.858</td>
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<tr>
<td>ePTO Cold Charge</td>
<td>1.248</td>
<td>920.246</td>
<td>283.250</td>
<td>315.853</td>
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<tr>
<td>ePTO Warm Charge</td>
<td>0.731</td>
<td>712.890</td>
<td>224.050</td>
<td>250.621</td>
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<tr>
<td>Improvement: cold</td>
<td>98%</td>
<td>79%</td>
<td>80%</td>
<td>78%</td>
</tr>
<tr>
<td>Improvement: Warm</td>
<td>99%</td>
<td>84%</td>
<td>84%</td>
<td>83%</td>
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</table>
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Responses, Barriers, Proposed Future Research

- Responses to Prior year comments
  - This project was not reviewed last year

- Remaining Barriers and Challenges
  - Changes in Utility priorities has made it difficult to find willing participants to donate capital equipment to the project for the period 3 demonstration
    - Odyne is working with DOE to revise the program plan to allow a depreciation cost-share rather than the full equipment, thus eliminating the capital burden on the Utility participants

- Proposed Future Research
  - Period 2: Complete full year simulation of work truck fuel savings based on NREL driving and stationary test results (In Process)
  - Period 2: Secure 2 Utility partners to partner with for Period 3 demonstration
  - Period 2: Assemble hybrid systems on Utility partners chosen platform
  - Period 3: Deliver demonstration vehicles (10 total) and perform 1 year demonstration and analysis

Any proposed future work is subject to change based on funding levels
Summary

- Odyne and its project partners are working towards greater acceptance, improved fuel savings, and increased ROI of the Plug-in Hybrid/Jobsite Electrification system for Medium-Heavy-Duty Work Truck through:
  - Increased Driving Fuel Economy
  - Algorithms and/or inputs to manage the drive/work energy balance
  - Improved Full Year Fuel Savings
  - Reduced system cost, system simplification

- Advancements have been made in the areas of:
  - Development of driving, stationary duty cycles and full-year model for the work truck
  - Lab results demonstrating the driving and stationary fuel and emissions improvements of the Odyne PTO based hybrid and electrifications system.
  - Development of a modular system approach to medium and heavy-duty vocational vehicle electrification

- Remaining Deliverables:
  - Analytical Demonstration of 50% reduction in Work Truck fuel use
  - Secure, Build and monitor the 10 vehicle demonstration fleet

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